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Effects of Curved Approach Paths and Advanced Displays on Pilot Scan Patterns

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SUMMARY

Newer generations of aircraft will utilize advanced displays, better automation systems, and better electronics. These advances coupled with similar advances in ground navigation aids should allow pilots to perform precision advanced flight maneuvers, such as curved instrument landing approaches, which are not currently possible with a conventionally equipped aircraft. To assess the effect on pilot scan behavior of both advanced cockpit and advanced maneuvers, a series of straight-in and curved landing approaches were performed in the Terminal Configured Vehicle (TCV) simulator at the Langley Research Center. Two comparisons of pilot scan behavior were made. First, scan behavior during straight-in approaches in the TCV simulator was compared with scan behavior previously obtained in a conventionally equipped simulator. Second, pilot scan behavior in the TCV simulator during straight-in approaches was compared with scan behavior during curved approaches. The results indicate that the pilots used very similar scanning patterns during the straight-in approaches in the conventional and advanced cockpits. However, for the curved approaches, pilot attention was shifted to the electronic horizontal situation display (moving map), and a new eye scan path appeared between the map and the airspeed indicator. Because the pilots spent less time looking at the electromechanical instruments, the graphic displays should be made very reliable and accurate. The very high dwell percentage and dwell times during the final portions of the approaches on the electronic displays in the TCV simulator were taken to indicate that the electronic attitude direction indicator was well designed for these landing approaches.

INTRODUCTION

Initial research into pilot scan behavior conducted at the Langley Research Center has generally been directed at quantifying pilot scanning behavior in commercial transport aircraft equipped with conventional instrument panels. These tests were carried out with airline transport trainers and in-house simulators (refs. 1 to 3). Specifically, the instrument approach phase of flight was studied because of its traditionally higher risk factor. In the analysis of these data, it was recognized that different segments of the landing approach involved different piloting tasks such as maintaining level flight, intercepting glide slope, maintaining constant rate of descent on glide slope, and flaring. It was hypothesized that these different piloting tasks would affect the resulting pilot scan behavior as indicated by the percentage of dwell times spent on the individual instruments. The data did show that indeed there were very slight shifts in pilot attention during these different segments.

Newer generations of aircraft will have different instrument panels with cathode-ray tubes (CRT's) instead of the conventional electromechanical dial indicators. These new CRT displays will allow for new formats such as pictorial representations of the runway. Reference 4 presents the results of a simulator

study conducted with an electronic attitude display indicator (EADI) to evaluate various display formats for use in the Terminal Configured Vehicle Program (ref. 5). Initial pilot scanning analysis of the combination of the EADI and horizontal situation indicator (HSI) display (ref. 6) indicated that for instrument landing approaches, the percent of usage was about the same as that for the conventional electromechanical flight director which the EADI replaced.

Advanced ground equipment for air traffic control such as the microwave landing system (MLS) and the discrete address beacon system (DABS) will offer the pilot instrument landing approach information of higher accuracy and in greater quantity than has been available at any previous time. These two systems as well as new displays and control systems such as those used in the TCV Program should allow pilots to take on instrument flight tasks, such as precise curved descending approaches, that were almost impossible with current aircraft.

Multiple curved descending approaches offer significant possibilities for noise control, traffic separation, trailing vortex avoidance, and other problems currently encountered in the present air traffic control system. The newer aircraft which have not only CRT displays of attitude, but also moving map displays replacing the heading indicator, should give the pilots precise control of the airplane on these more complicated approach paths (ref. 7). These developments raised the questions: How will the pilot visual workload be affected by these new approach paths and displays compared with current approach paths and displays? Will the displays be adequate for the new tasks?

To address these questions, a series of instrument approaches have been conducted in the Terminal Configured Vehicle (TCV) Aft Flight Deck simulator at the Langley Research Center. These tests were designed to compare the pilot scan patterns in straight-in landing approaches for conventional and advanced cockpits and the pilot scan patterns for straight-in and curved instrument landing approaches in advanced cockpits. The data analyzed were instrument dwell percentages, dwell times, and transition percentages. Additional data analyzed for the approach-path comparison were the dwell percentages and dwell times on the symbols within each of the electronic displays.

ABBREVIATIONS

ADI attitude direction indicator

CRT cathode-ray tube

DABS discrete address beacon system

EADI electronic attitude display indicator

EHSI electronic horizontal situation indicator

HSI horizontal situation indicator

ILS instrument landing system

MLS microwave landing system

NCDU navigation computer display unit

TCV Terminal Configured Vehicle

VCWS velocity control wheel steering mode

VSI vertical speed indicator

EQUIPMENT AND TESTS

Simulator

These experiments were conducted in a fixed-base simulator designed to match the aft flight deck in the TCV airplane. The interior of the simulator is shown in figure 1 and is described in detail in references 4 to 7. The cockpit is representative of an advanced transport aircraft with a computerized flight control system involving a fly-by-wire concept. The control handles (brolly) have been redesigned so that the CRT displays can be located directly in front of the pilot without any visual or physical obstructions.

The display formats of the two main CRT's (figs. 2 and 3) combined conventional needle pointer and newer pictorial elements as well as digital display features. The EADI (fig. 2) presented lateral and vertical displacement errors, relative ground track, and longitudinal acceleration as indicator displacements; pitch and roll attitude, runway, and flight-path angle as pictorial elements; and digital altitude below 762 m. The EHSI (fig. 3) presented planned ground track and predicted ground track for the next 90 seconds in a map format. Digital ground speed, map scale, and magnetic track were also presented. The EHSI was flown in the mode. The rest of the displays were conventional needle point instruments located in their traditional positions around these electronic displays and are listed with the EHSI and EADI as follows:

EHSI
EADI
Airspeed indicator
Altitude indicator
Altitude rate indicator

Marker beacon
Engine instruments
Select panel
Mode control panel

A highly modified commercial oculometer was used in this study to measure the pilot's eye point of regard. The modifications consisted of a redesigned electro-optic head resulting in a unit about one-third the original size. Software changes resulted in a simpler operating system, and an on-line video-recorded pilot scanning activity which allowed the operator to observe in real time the system performance. The elctro-optic unit and a camera which monitored the pilot were mounted on the glare shield and were partially hidden by a black felt cloth (fig. 1). Appendix A of reference 3 gives a more detailed description of the oculometer hardware.

Pilots and Piloting Tasks

Three NASA test pilots who were very familiar with the TCV airplane and simulator participated in these tests. Each pilot flew both paths three times resulting in a total of 18 landing approaches.

The pilots made simulated instrument approaches on either the straight-in approach path or the curved descending approach path, as shown in figure 4. The straight-in approach path started approximately 13 kilometers from the runway at an altitude of 460 meters. The pilot's task was to maintain constant altitude and ground track on segment 1, intercept the 3° glide slope on segment 2, follow it down to the runway on segments 3 and 4, and land on segment 5. The curved descending approach path started at an altitude of 1500 meters at a point opposite the runway. The pilot's task was to immediately establish a 3° descending flight path while meeting altitude and speed requirements at each of three waypoints. The final turn (segment 3) ended at a point only 1700 meters from the end of the runway; consequently, the pilot did not have much time left to correct for any misalignment which might have occurred.

All approaches were made in the velocity control wheel steering mode (VCWS) described in reference 5. In this mode the pilot used the control handles to establish the bank angle and flight-path angle. The VCWS system then maintained the aircraft at those conditions without further need for pilot input. The airspeed was set by the pilot on a center instrument panel, and the throttles were automatically actuated to establish and maintain the selected airspeed.

One of the experimenters functioned as copilot in all the tests. His duties were to perform configuration and display mode changes in response to the pilot's call-outs.

DATA ACQUISITION AND ANALYSIS

The oculometer data were recorded by the simulation computer 32 times per second along with appropriate vehicle and display parameters so that off-line data analysis could be performed. The following parameters were recorded:

- Time
- Lookpoint, X-coordinate
- Lookpoint, Y-coordinate
- Pupil diameter
- Track/no track
- Trim setting
- Fore-aft brolly handle position
- Rotary brolly handle position
- Throttle position
- Rudder pedal position
- Altitude
- Airspeed
- Altitude rate
- Discrete code
- Latitude
- Longitude
- Pitch attitude
- Roll attitude
- Yaw attitude
- Pitch rate
- Roll rate
- Yaw rate
- Commanded airspeed

This data analysis consisted of obtaining a first-order Markov transition matrix of the instruments scanned. The analysis also included determining the mean and standard deviation of the dwell times. The data were analyzed separately for each of the five segments of the approach (fig. 4). Data from corresponding segments were then compared.

In addition to analyzing the between-instrument transitions, the EADI and EHSI were divided into symbol areas, and pilot scanning behavior with these instruments was analyzed. The names of the symbols considered for each display are listed as follows:

EADI	EHSI
Airplane symbol	Magnetic track
Roll altitude	Own ship
Glide slope	Flight path
Localizer	Digital speed
Altitude	
Flight-path wedges	
Pitch reference	
Horizon	
Acceleration	
Runway	

For data analysis these symbols were broken down into rectangular areas, lines, or dots. Figures 5 and 6 show these areas for the EADI and the EHSI. If the pilot's lookpoint was within or close to any symbol (within 0.75 visual degrees), the pilot was considered to be looking at it. The resulting symbol boundaries are shown in these figures.

Some of the symbols (6 to 10 of the EADI) moved on the CRT in response to aircraft state and pilot inputs making it possible for two or more areas to overlap. Currently, it is impossible to determine which symbol the pilot was really attending to. However, in these tests only two symbols presented any real problem, the flight-path wedges in the EADI and the own ship symbol in the EHSI. In both cases it was decided that when overlaps involving these symbols and any other symbol occurred and the pilot was detected looking at that overlap, then the analysis program would assume that the pilot was looking at the flight-path wedges or the airplane symbol. Based on pilots' comments these were the important pieces of information needed to control the airplane.

RESULTS

Conventional Versus Advanced Cockpit

Scan behavior of airline pilots performing ILS approaches in a training simulator have been documented in reference 3. Data taken from that report on manually controlled, no-turbulence approaches are compared with data from the straight-in ILS approaches of the current study. The dwell percentage and aver-

age dwell times of five instruments common to both studies for the first four segments of the approach are listed in table I. These segments corresponded to those reported in reference 3.

Simulator differences.- The two simulations compared herein differ in two ways: type of displays and type of vehicle attitude control system. The study reported in reference 3 used all electromechanical displays (fig. 7). The current study had two CRT displays (EADI and EHSI; see figs. 2 and 3). The control system of reference 3 was a conventional attitude control system with a manually controlled throttle. The current study incorporated an advanced fly-by-wire control system in which the pilot commanded flight-path angle changes with fore-and-aft controller movements and the automatic control system modulated the elevator to establish the command flight-path angle. The roll attitude responses were similar in both studies except that in the present study the control system maintained the current roll attitude if the roll controls were centered. In addition, airspeed was maintained automatically by the control system to the airspeed which the pilot had set on the control mode panel.

Dwell percentage and average dwell time.- In this comparison of conventional versus advanced equipped aircraft, the discussion is limited to general trends evident in the data. For the following discussion the dwell percentages and dwell times consist of the averages of all the runs. The dwell percentage was derived by dividing the amount of time spent by the pilot looking at a particular display by the total time the oculometer was tracking the pilot. This figure was then multiplied by 100. The dwell time is the total time spent by the pilot looking at a particular display divided by the number of times the pilot looked at that display.

As table I shows, the dwell percentage on the EHSI, except for segment 1, is less than that for the electromechanical heading display. The dwell time, however, is roughly 3 times greater for the EHSI. The dwell percentages for the EADI and its electromechanical counterpart are roughly the same except for segment 4, in which it is 15 percent greater. The dwell time is greater for the EADI in all segments, and this difference increases as the airplane approaches the runway. For the rest of the instruments, electromechanical in both studies, the dwell percentages were lower in the advanced cockpit. The dwell times, however, were about the same for both aircraft cockpits. In addition, the total dwell percentages of these five instruments is less in the advanced cockpit than in the conventional cockpit except for segment 4, where they are the same.

Straight-in Versus Curved Approaches

Pilot scanning behavior for the TCV simulator was compared for the straight-in landing approach and the curved descending approach while using the same displays and flight control system. The approaches were divided into five segments for data analysis. These curved path segments were designed to correspond to the previous straight-in path segments (fig. 4). The last two segments of the curved approach corresponded exactly to the last two segments of the straight-in approach. The data are discussed in the following two sections.

Between-instruments scans.- The instrument dwell percentages and dwell times are summarized in table II for corresponding segments of the curved and straight approaches. For the electromechanical displays outside the CRT's, the dwell percentages are generally greater during the straight-in approach than during the curved approach. For the straight-in approaches the dwell percentage on the EADI slowly increased from 63 percent in segment 1 to 98 percent in segment 5. The EHSI dwell percentage decreased from 7 percent in segment 1 to 0 percent in segment 5. In the curved approaches, on the other hand, the EADI dwell percentage decreased from 57 percent in segment 1 to 44 percent in segment 2 before increasing to 98 percent in segment 5. The EHSI dwell percentage increased from 23 percent in segment 1 to 40 percent in segment 2 before decreasing to 0 percent in segment 5. The sum of the dwell percentages for the EADI and the EHSI for the first three segments is about 10 percent greater in the curved approaches than in the straight-in approaches.

Figures 8 to 11 are schematic representations of the instrument shapes and relative locations used to show the transition percentages between instruments. The width of the line connecting the two instruments is proportional to the number of times a transition was made between the two instruments, regardless of the direction of the transition, divided by the total number of transitions. This number expressed as a percentage is indicated in the break in the line. The dwell percentage and dwell time (in parentheses) are given inside the instrument boundary. The straight-in approaches involved transitions between the EADI and three other instruments: airspeed indicator, EHSI, and altimeter with most transitions made to the airspeed indicator. The transitions to these instruments usually resulted in a transition, back to the EADI, as evidenced by the lack of a substantial percentage of transitions between the other instruments. In the curved approaches, most of the transitions were between the EADI and two other instruments: airspeed indicator and EHSI with an additional transition path appearing between the airspeed indicator and the EHSI. The majority of the transitions occurred between the EADI and the EHSI. Almost twice as many transitions per second were made in the curved approach segments 2 and 3 as in the straight approach; most of these were to the EHSI and resulted in fewer transitions between the EADI and the airspeed indicator.

Within-instruments scans.- Both the EADI and EHSI were analyzed to determine the percent usage of the major symbols of each display. Table III shows these data for the EADI. Ten symbols were analyzed. The first group of five were basically nonmoving symbols (airplane, altitude, or fixed scales with moving pointer: i.e., glide slope, localizer, and roll attitude). The next group of five consisted of more pictorial symbols that moved around in the display as a function of state variables (flight-path wedges, pitch reference, horizon, acceleration symbol, and runway). As expected, use of the roll attitude indicator was greater in the curved approach than in the straight approach. In almost all segments the localizer was used almost twice as much in the curved approach as in the straight-in approach. However, there was no change in localizer dwell times for the two approach paths. The EADI symbol used the most was the flight-path wedges. The next most often used element was the airplane symbol. These twp symbols combined accounted for 30 to 40 percent of the dwell time spent in the EADI. These two symbols overlapped each other in segments 3 and 4, making it almost impossible to distinguish which one the pilot was looking at. To alleviate this overlap and clutter, the pilots have had the aircraft symbol biased

up 5° in the TCV airplane. For the curved approach path, the pilots used the flight-path wedges the least (20 percent) in segment 2 (where roll attitude and localizer usage was greatest), and the most (31 percent) in segment 5. For segment 5 (flare) the combined dwell percentage of flight-path wedges, aircraft, and runway elements is almost 50 percent. In addition to the increased dwell percentage of these three symbols in segment 5, the dwell times are almost double that of the other segments.

Table IV presents the within-instrument data for the EHSI. Because the EHSI dwell percentages of the last two segments were essentially zero, only data for the first three segments are presented. In addition, because of the low percentages for the straight-in approaches, no meaningful comparisons can be made.

Discussion of Low Dwell Percentages Within Instruments

As mentioned previously in the section "Data Acquisition and Analysis," the method of analysis for dwells upon display symbols inside the graphic displays is more restrictive. Because of the proximity of several symbols, the boundary around each symbol was kept as small as possible to avoid combinations of display symbols. However, the boundary had to be kept large enough to try to account for the width of the fovea. Consequently, as figures 5 and 6 show, there are areas in each display where the pilot could be looking, but the data analysis does not indicate any display symbol being scanned. Perhaps improved analysis techniques and a better understanding of the ways humans process visual information will permit the development of models which give probabilities as to which elements are being attended to when the pilots are not looking directly (with foveal vision) at any graphic element.

DISCUSSION

The fact that not all dwell times in the graphic display could be accounted for may be fortuitous. Both the within-instrument dwell percentage and the between-instrument dwell percentage (tables I to IV) show a consistent trend with respect to experimenters' and pilots' subjective judgments of workload. The amount of unaccounted for dwell percentage decreases with those tasks considered to involve greater workload. As the workload goes up, the pilots tend to look at information more closely. It is, therefore, tempting to speculate that the lack of precise pilot lookpoint could be a measure or at least an indication of decreased pilot workload. Controlled tests should be performed to establish this link.

The increase in dwell percentage and average dwell time in the curved approach is very likely due to the fact that the pilot makes additional control inputs. Reference 8 reported that the dwells associated with control inputs were longer than those involving just the monitoring of a display.

One advantage of the advanced displays is that more information can be located in one display although the pilots do not use that display any more (same dwell percentage) than the electromechanical attitude direction indicator

(ADI). The EADI as tested in this study seems to be well designed. However, since the pilots tend to use the secondary instruments (cross-check instruments such as airspeed, altitude, and rate-of-climb indicators) less, the advanced cockpit systems designer must provide reliable data, computer, and graphics systems so that the display on the CRT is accurate and dependable. In addition, the designer may wish to consider using the EADI as a place for the master caution and warning messages, since the pilots spend most of their time looking at that display. Because it is a CRT display, alphanumeric data could be easily inserted. In the curved approach path the pilots make even fewer cross-checks to the secondary instruments and spend over 80 percent of their time looking at the EADI and EHSI, a finding that strengthens the foregoing points.

For the curved approaches, both EADI and EHSI are equally important to the pilot (with almost same dwell percentage). The increased use of the EHSI caused more total transitions and lowered the average dwell time on the EADI. Since airspeed is also important to the pilot, a new transition link appears in the curved approaches between the EHSI and the airspeed indicator. For instrument layout design, these three instruments should be adjacent to each other with the relative locations similar to those in these tests, i.e., the CRT's should be located one over the other with the airspeed indicator to one side (by convention, this would be the left side). Locating the two CRT's side by side would make the pilot's scanning task more difficult. The pilot would be forced to make long transitions from the right hand CRT to the airspeed. Therefore, that instrument arrangement would probably not be advisable.

Airspeed information could be added to both the EADI and EHSI. Airspeed error was available as an option in the EADI but the pilots did not choose to use it. Ground speed was displayed in the EHSI in the lower right hand corner, but it was fairly small and used less than 2 percent of the time spent in the EHSI. Consideration should be given to putting absolute airspeed in these two displays because of the transitions to the airspeed indicator. Perhaps it could be located next to the flight-path wedges in the EADI and next to the own ship symbol in the EHSI.

CONCLUSIONS

A series of straight-in and curved landing approaches were performed to assess the effect on pilot scan behavior of advanced cockpit and maneuvers. On the basis of the results of these tests and comparisons with data from previous pilot scan research, the following conclusions and recommendations can be drawn:

1. Although additional information is presented on the graphic displays, the pilots' dwell percentages are comparable with those which occur with electromechanical displays in accomplishing the same task. This similarity indicates that these graphic displays are apparently well designed for the instrument landing task.

2. Curved flight paths shift the pilot's attention from the EADI to the combination EADI and EHSI. Because of the increased importance of the EHSI in the curved flight path, a new transition path occurs between the EHSI and the airspeed indicator.

3. New transition paths can occur with the increased complexity of maneuvers allowed by better display designs. These new transition links may dictate a different display panel arrangement. Other flight tasks should be evaluated to verify whether or not current panel arrangements are satisfactory.

4. Because of their high dwell percentages, consideration should be given to using the EADI and EHSI as part of the master caution and warning display.

5. Finally, it should be emphasized that consideration be given to the level of reliability needed in these advanced display and control systems. Because the pilots spend less time looking at each cross-check instrument with these systems, their reliability and accuracy needs to be considered.

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TABLE I.- COMPARISON OF DWELL PERCENTAGES AND AVERAGE DWELL TIMES FOR CONVENTIONAL (C) AND ADVANCED (A) COCKPITS

Instrument	Dwell percentage, %, and dwell time, (sec), for -							
	Segment 1		Segment 2		Segment 3		Segment 4	
	C	A	C	A	C	A	C	A
Attitude indicator[a]	67 (1.3)	63 (2.2)	77 (2.0)	69 (3.5)	75 (1.7)	75 (6.5)	89 (2.5)	94 (13.1)
Heading indicator[a]	7 (0.3)	7 (0.8)	6 (0.2)	3 (0.7)	6 (0.2)	1 (0.7)	4 (0.2)	1 (0.9)
Airspeed indicator	13 (0.5)	6 (0.7)	10 (0.4)	4 (0.5)	12 (0.4)	3 (0.7)	8 (0.4)	1 (0.4)
Altitude indicator	6 (0.4)	3 (0.5)	2 (0.1)	1 (0.5)	1 (0.2)	2 (0.8)	2 (0.2)	1 (0.4)
Vertical speed indicator	4 (0.2)	1 (0.2)	3 (0.2)	0 (0.2)	3 (0.2)	----- -----	3 (0.2)	0 (0.2)
Total percentage	97	80	98	77	97	81	97	97

[a]CRT displays in advanced cockpit.

TABLE II.- COMPARISON OF INSTRUMENT DWELL PERCENTAGES AND AVERAGE DWELL TIMES FOR CURVED AND STRAIGHT-IN APPROACHES

Instrument	Dwell percentage, %, and dwell time, (sec), for -									
	Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Straight	Curved	Straight	Curved	Straight	Curved	Straight	Curved	Straight	Curved
EADI	63 (2.2)	57 (2.3)	69 (3.5)	44 (1.7)	75 (6.5)	59 (2.6)	94 (13.1)	94 (13.4)	98 (12.5)	98 (8.3)
EHSI	7 (0.8)	23 (1.3)	3 (0.7)	40 (1.6)	1 (0.7)	31 (1.8)	1 (0.9)	1 (0.8)		
Airspeed indicator	6 (0.7)	7 (0.7)	4 (0.5)	4 (0.5)	3 (0.7)	2 (0.5)	1 (0.4)	1 (0.3)		0 (0.2)
Altitude indicator	3 (0.5)	0 (0.2)	1 (0.5)	0 (0.6)	2 (0.8)	0 (0.2)	1 (0.4)	0 (0.2)		
Vertical speed indicator	1 (0.2)	0 (0.1)	0 (0.2)	0 (0.6)			0 (0.2)		1 (1.2)	
Engine indicators	0 (1.2)		0 (0.9)		1 (0.8)		0 (0.4)			
Select panel	1 (0.4)	0 (0.2)	0 (0.3)	0 (0.4)	0 (0.1)	0 (0.4)				
Mode panel	3 (2.2)	1 (1.1)	1 (0.6)	1 (1.2)	0 (1.4)	1 (2.8)	0 (0.3)	0 (0.3)		
Total percentage	84	88	78	89	82	93	97	96	99	98

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TABLE III.- COMPARISON OF WITHIN-EADI DWELL PERCENTAGES AND DWELL TIMES FOR CURVED AND STRAIGHT-IN APPROACHES

Symbol	Dwell percentage, %, and dwell time, (sec), for -									
	Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
	Straight	Curved	Straight	Curved	Straight	Curved	Straight	Curved	Straight	Curved
Airplane	14 (0.3)	15 (0.3)	11 (0.3)	10 (0.3)	9 (0.4)	9 (0.3)	9 (0.3)	12 (0.4)	7 (0.4)	12 (0.8)
Roll attitude	5 (0.5)	6 (0.7)	3 (0.4)	14 (0.7)	2 (0.5)	7 (0.7)	3 (1.1)	3 (0.4)	0 (0.5)	1 (0.1)
Glide slope	10 (0.4)	8 (0.4)	12 (0.5)	9 (0.4)	11 (0.5)	11 (0.4)	9 (0.5)	5 (0.3)	3 (0.3)	1 (0.3)
Localizer	4 (0.3)	6 (0.3)	4 (0.4)	10 (0.4)	4 (0.4)	8 (0.3)	5 (0.5)	6 (0.3)	1 (0.4)	4 (0.3)
Altitude	1 (0.4)	NA	2 (0.6)	1 (0.4)	3 (0.7)	0 (0.2)	5 (0.5)	1 (0.3)	7 (0.4)	7 (0.4)
Flight-path wedges	24 (0.4)	26 (0.5)	22 (0.6)	20 (0.6)	21 (0.6)	23 (0.4)	24 (0.5)	28 (0.5)	29 (0.6)	31 (0.8)
Pitch reference	3 (0.3)	2 (0.3)	2 (0.3)	3 (0.3)	2 (0.3)	4 (0.4)	4 (0.3)	7 (0.5)	3 (0.6)	2 (0.5)
Horizon	3 (0.2)	1 (0.3)	2 (0.4)	1 (0.3)	0 (0.3)	1 (0.3)	2 (0.3)	1 (0.3)	1 (0.2)	0 (0.2)
Acceleration	3 (0.2)	4 (0.3)	4 (0.3)	4 (0.3)	2 (0.3)	5 (0.3)	1 (0.2)	9 (0.4)	3 (0.3)	5 (0.6)
Runway	2 (0.3)	NA	1 (0.3)	NA	4 (0.8)	4 (0.5)	7 (0.7)	2 (0.7)	6 (1.0)	10 (0.8)
Total percentage	69	68	63	72	58	72	69	74	60	73

TABLE IV.- COMPARISON OF WITHIN-EHSI DWELL PERCENTAGES AND DWELL TIMES

FOR CURVED AND STRAIGHT-IN APPROACHES

Symbol	Segment 1		Segment 2		Segment 3	
	Straight	Curved	Straight	Curved	Straight	Curved
Magnetic track	29 (0.4)	11 (0.7)	8 (0.7)	14 (0.5)	1 (0.2)	11 (0.5)
Own ship		6 (0.3)		4 (0.3)		16 (2.3)
Flight path	24 (0.6)	38 (0.7)	1 (0.2)	49 (1.0)	9 (0.2)	45 (1.2)
Speed		2 (0.3)		1 (0.4)		1 (0.7)
Total percentage	53	57	9	68	10	73

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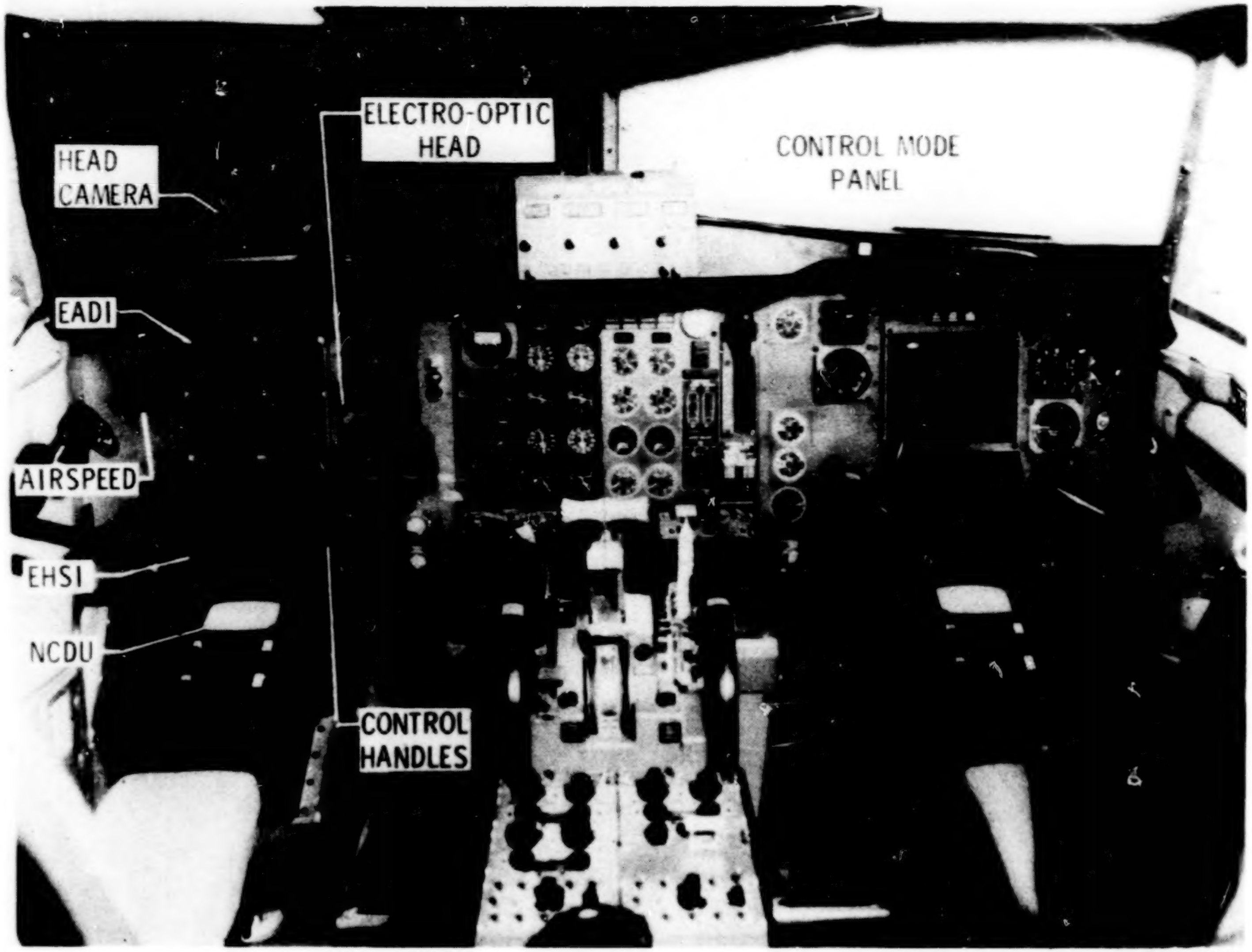

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Figure 1.- Interior of the Terminal Configured Vehicle simulator.

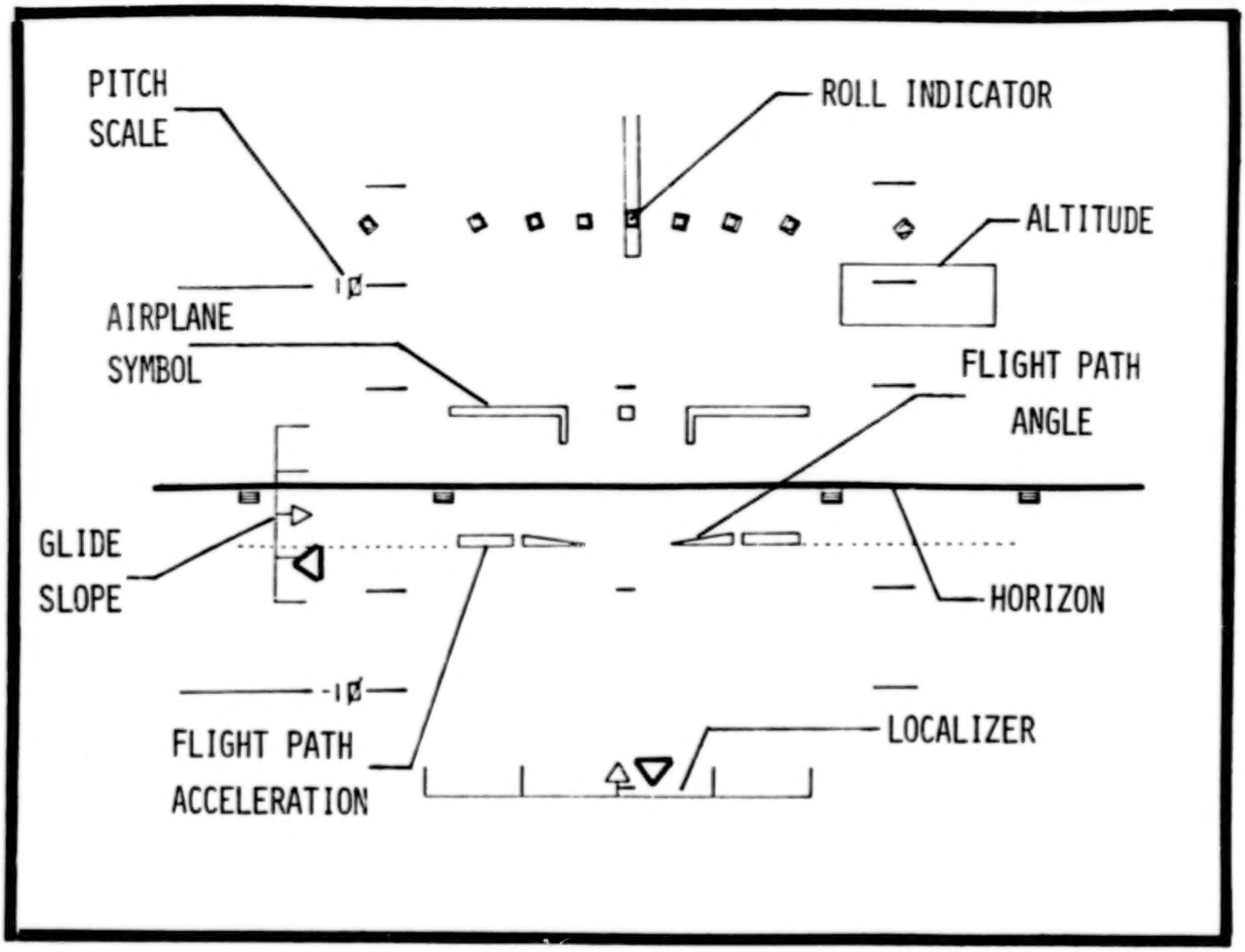

Figure 2.- EADI display.

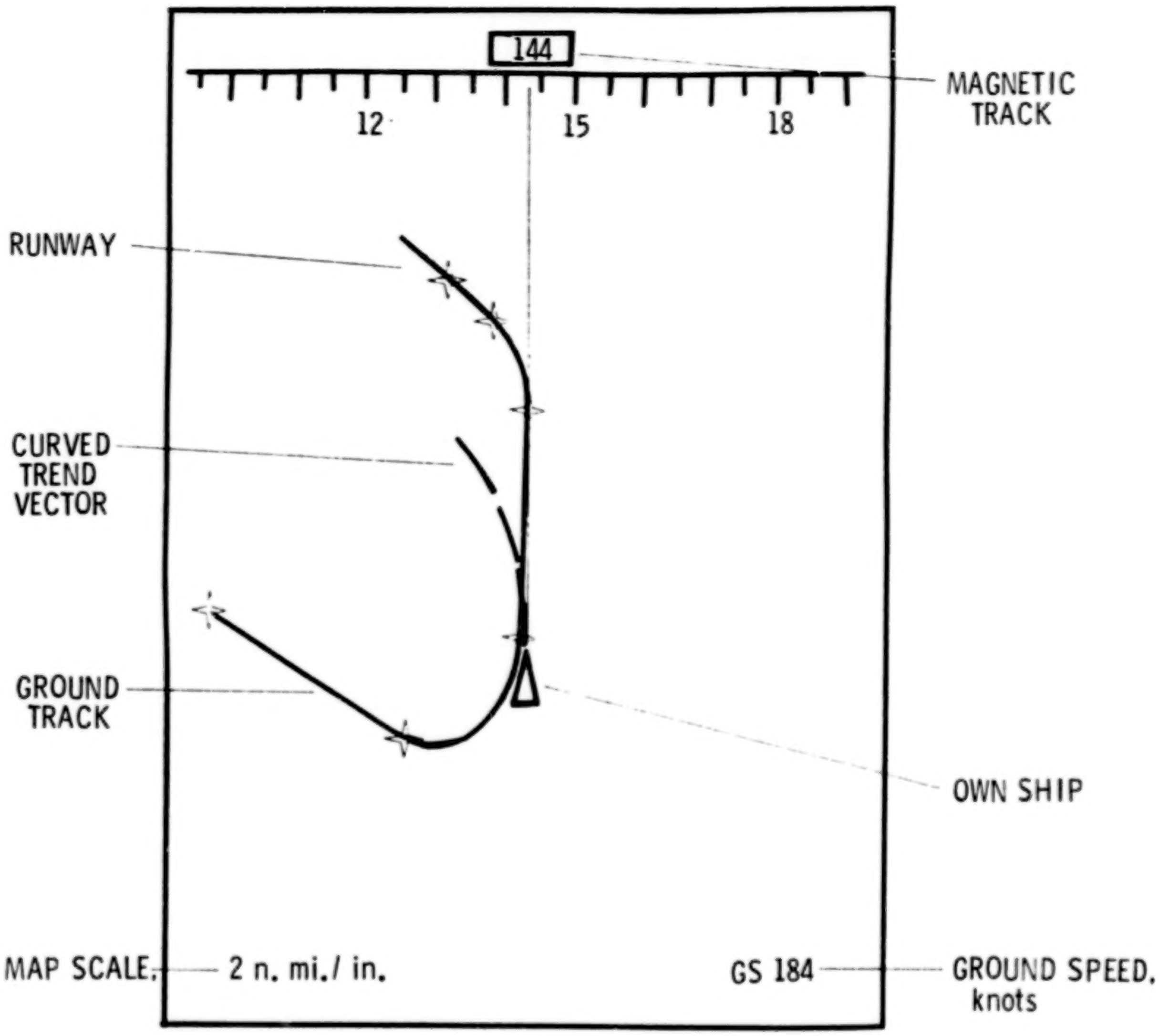

Figure 3.- EHSI display.

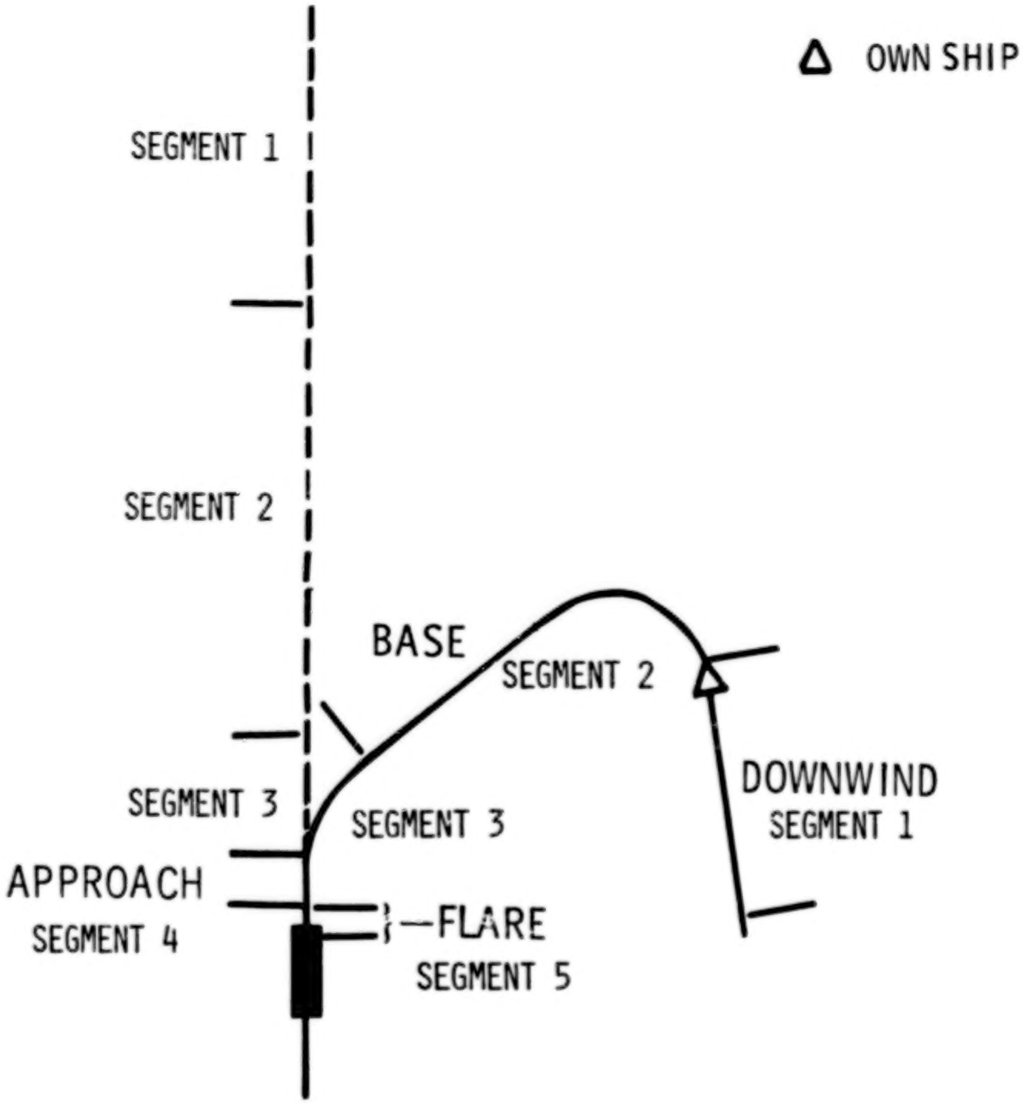

Figure 4.- Approach paths and segments in data analysis.

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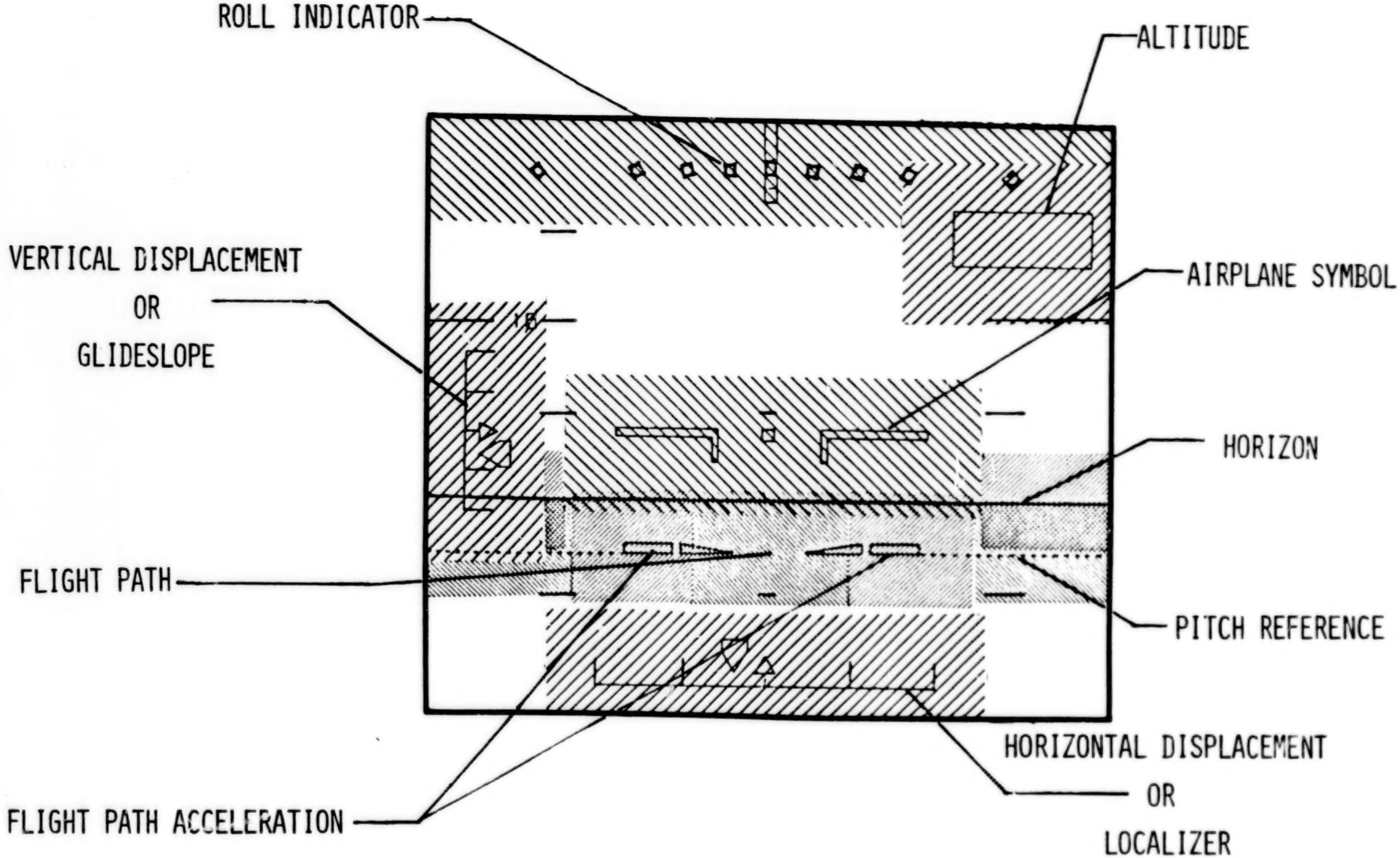

Figure 5.- EADI analysis areas. Wide hatching denotes fixed areas; narrow, moving areas.

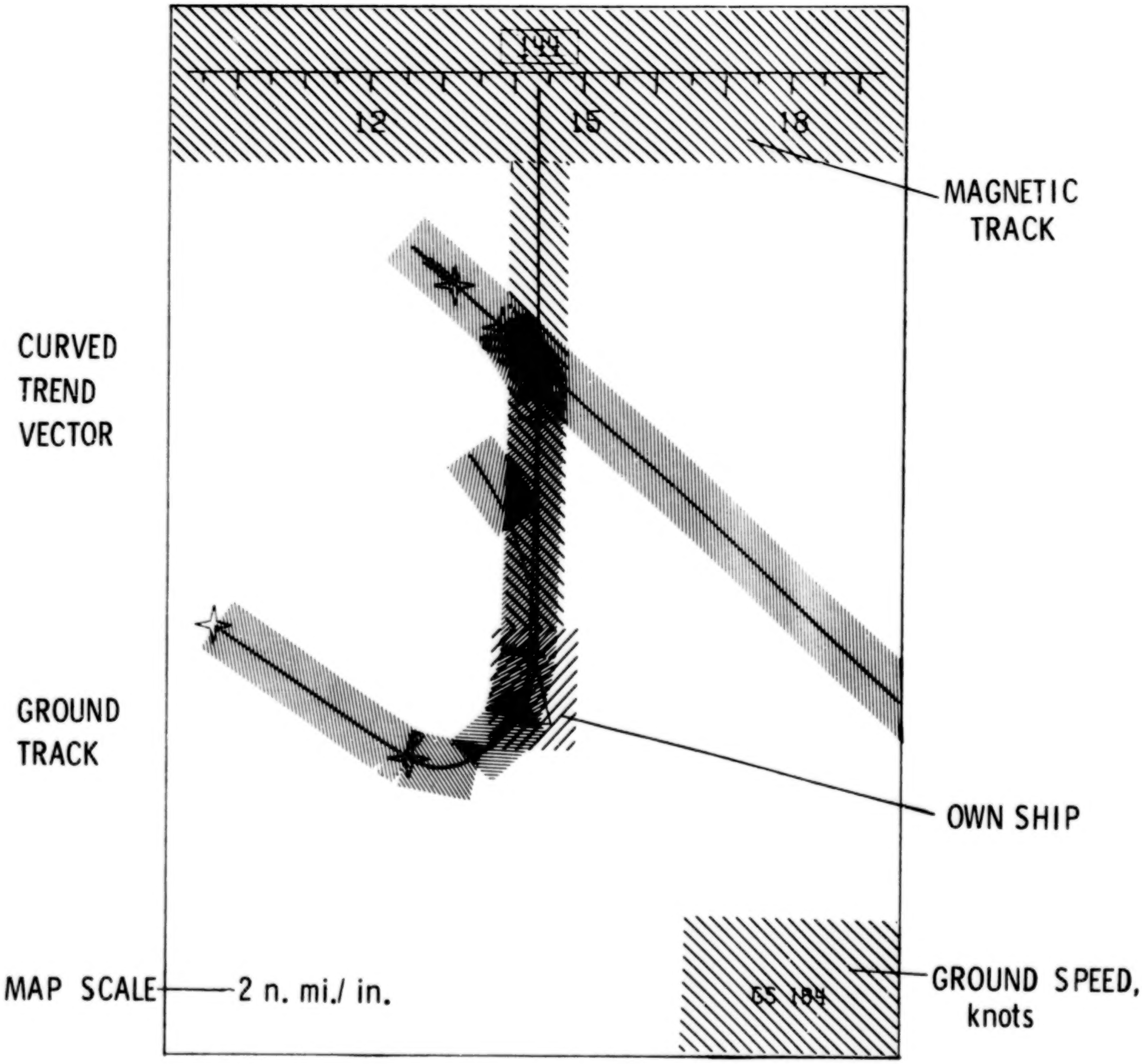

Figure 6.- EHSI analysis areas. Wide hatching denotes fixed areas; narrow, moving areas.

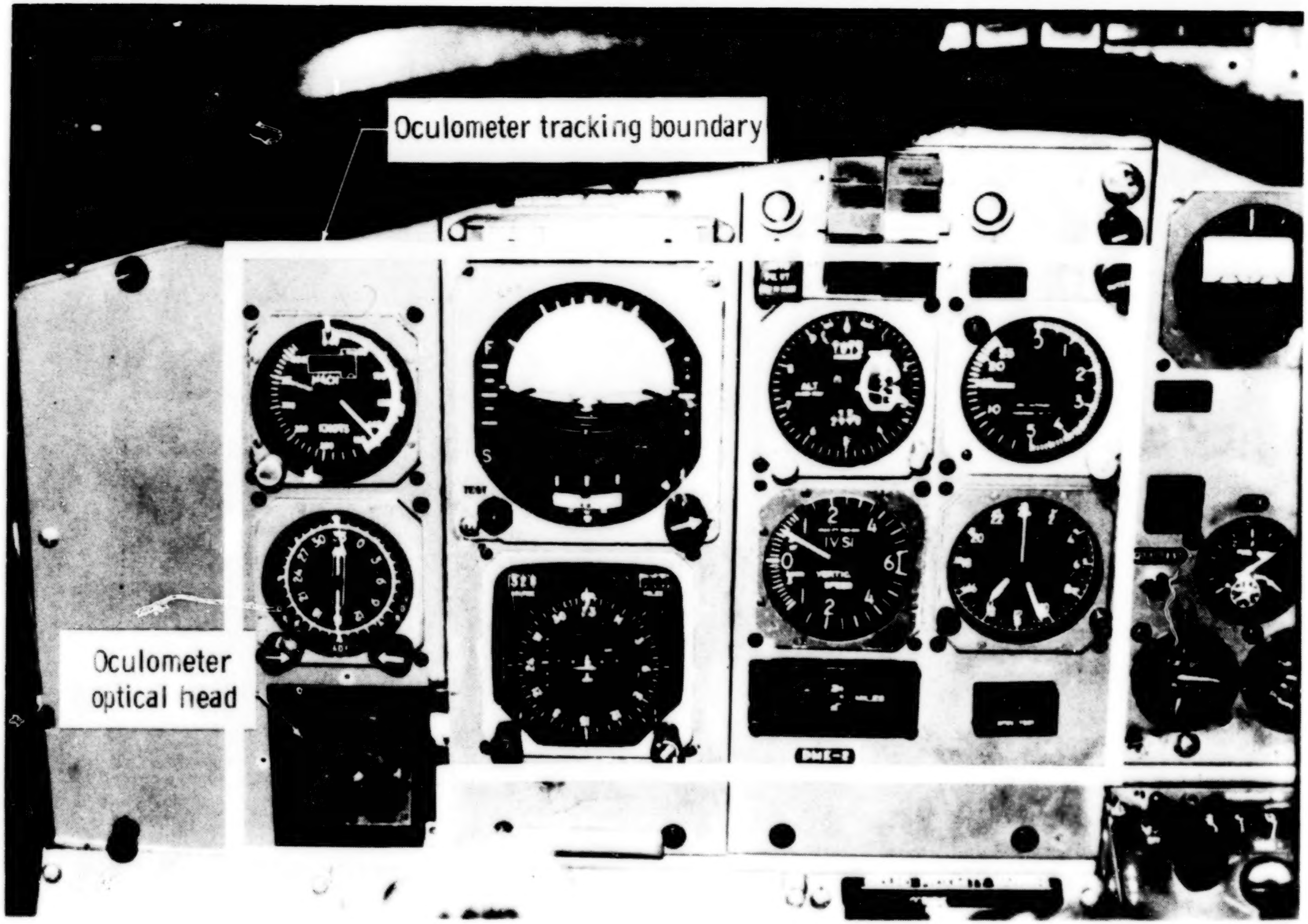

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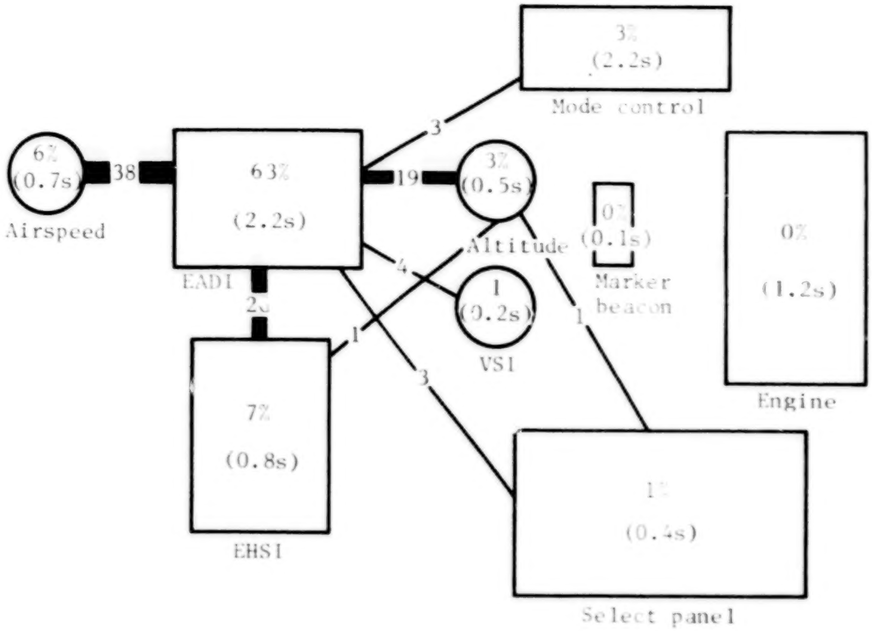
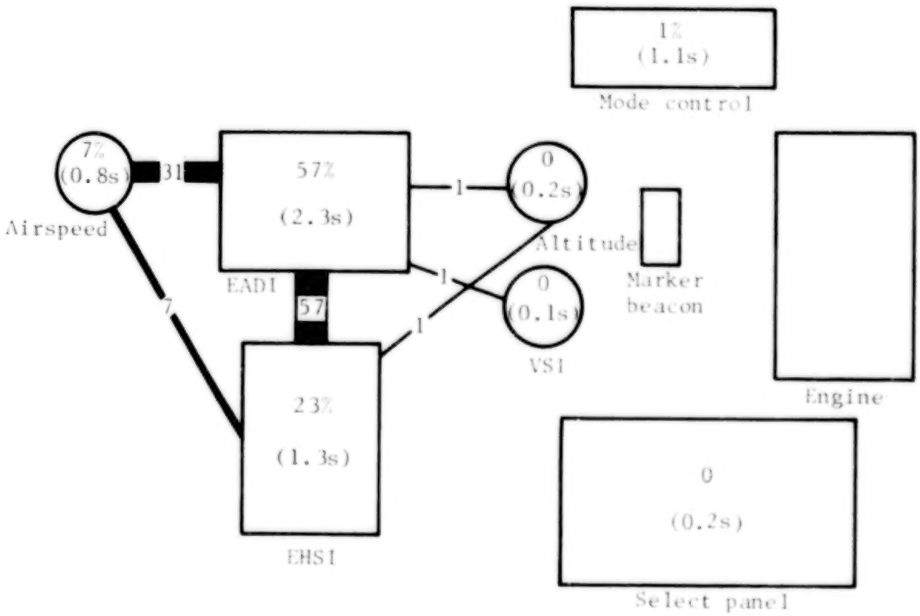
Figure 7.- Captain's flight instrument panel.

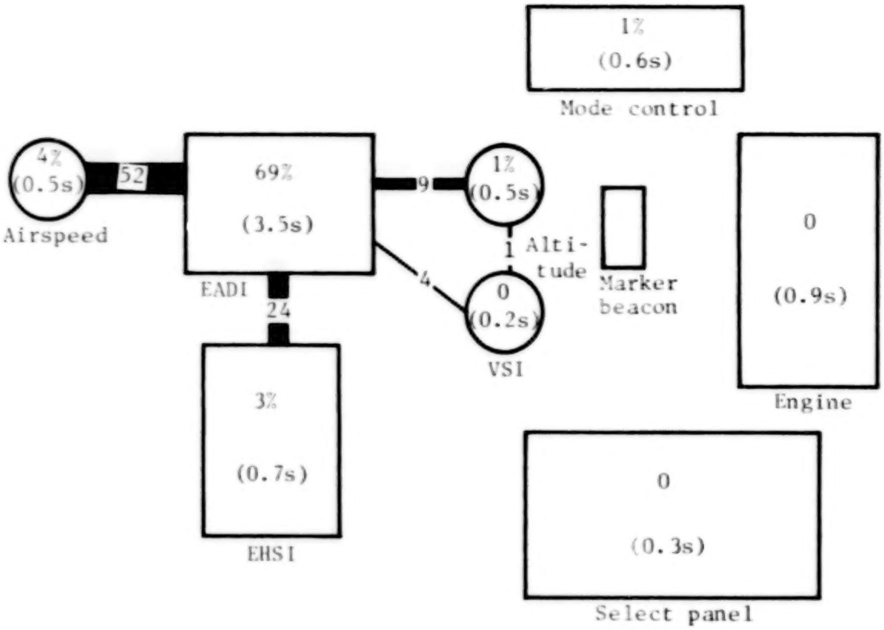


(a) Straight-in approach.

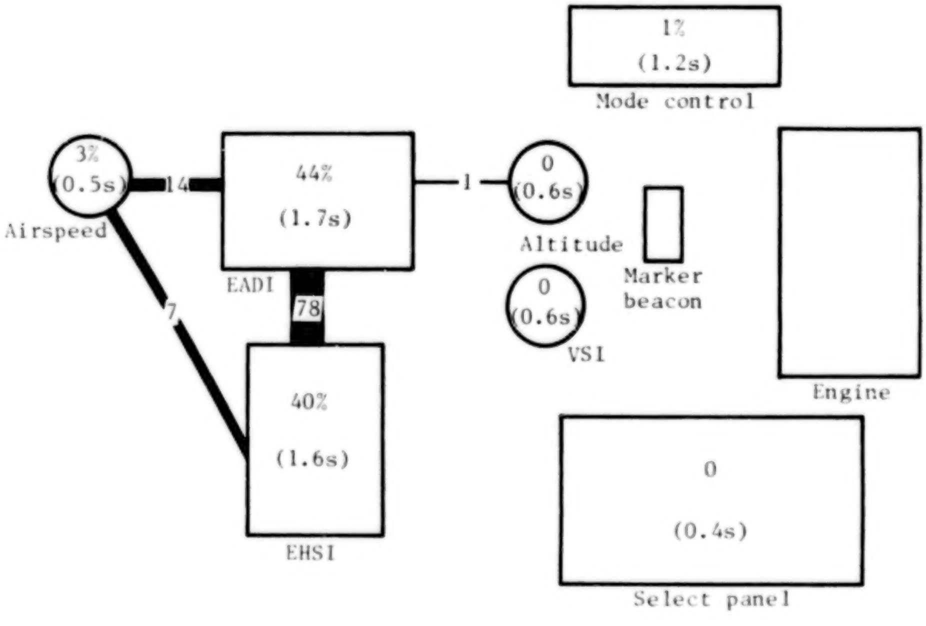


(b) Curved approach.

Figure 8.- Dwell times, dwell percentages, and transition percentages for curved vs straight-in approaches in segment 1. Absence of data indicates absence of pilot scan.

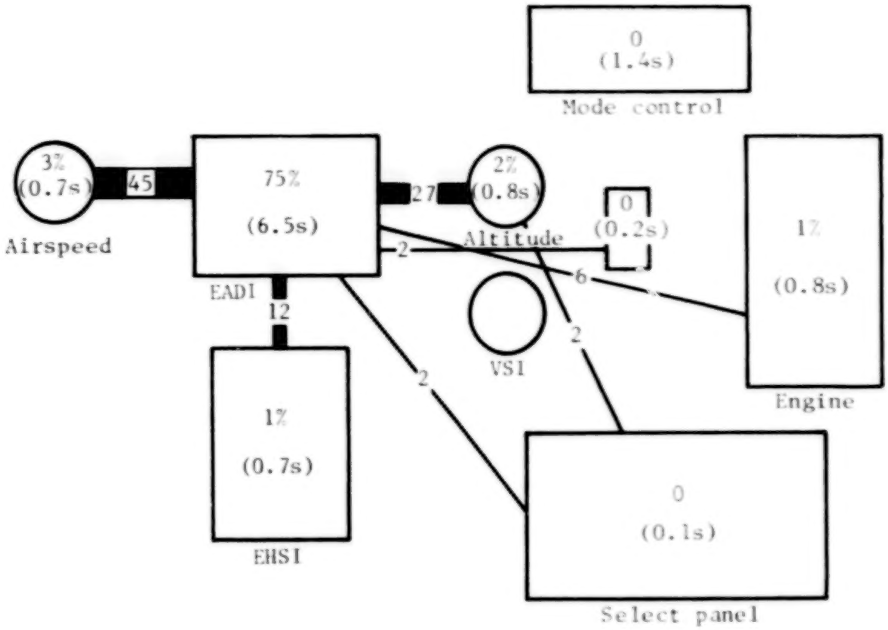


(a) Straight-in approach.

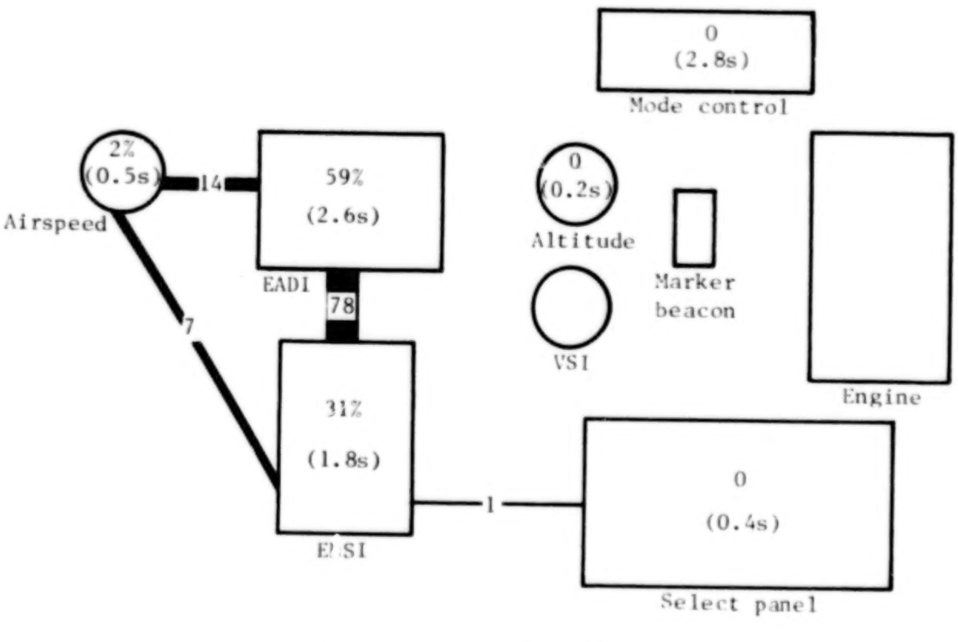


(b) Curved approach.

Figure 9.- Dwell times, dwell percentages, and transition percentages for curved vs straight-in approaches in segment 2. Absence of data indicates absence of pilot scan.

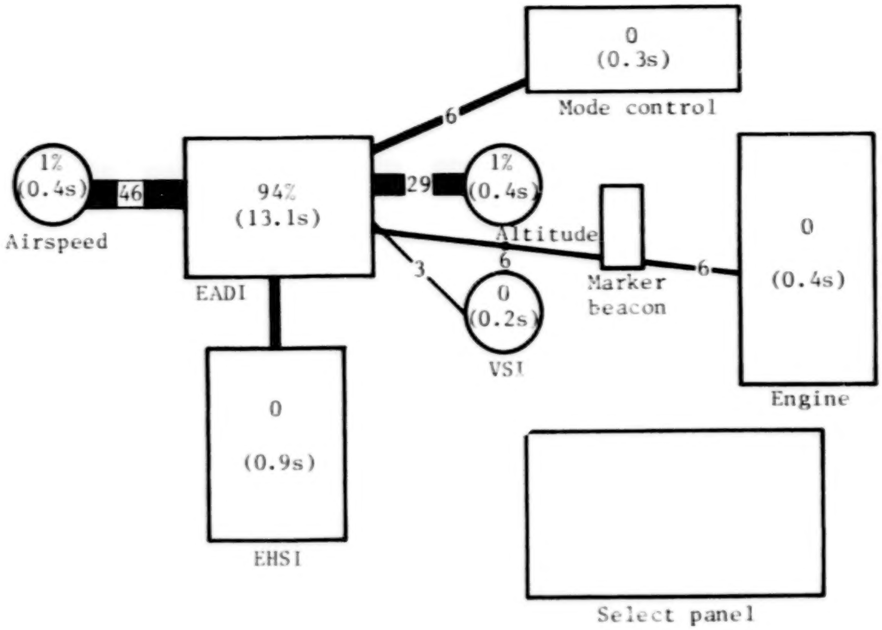


(a) Straight-in approach.

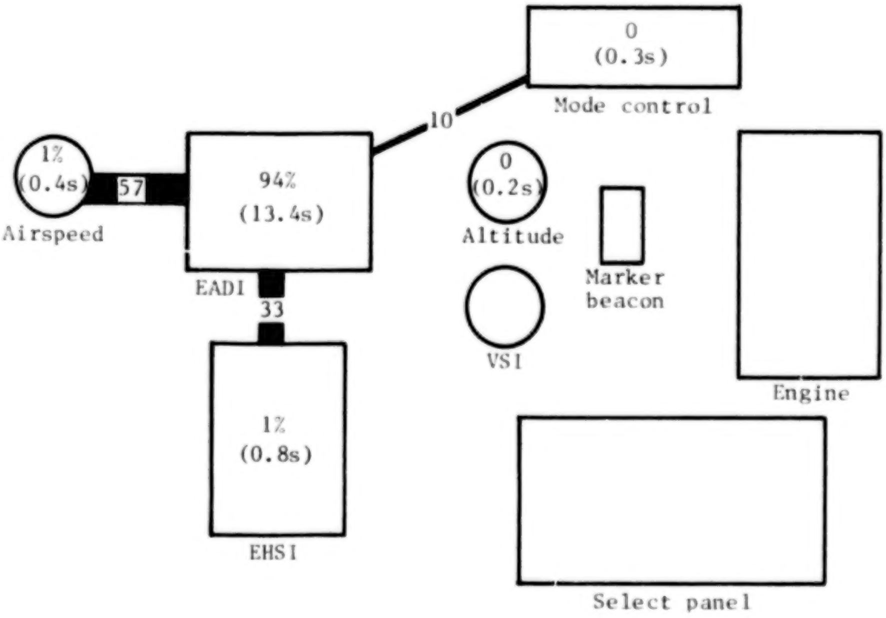


(b) Curved approach.

Figure 10. Dwell times, dwell percentages, and transition percentages for curved vs straight-in approaches in segment 3. Absence of data indicates absence of pilot scan.



(a) Straight-in approach.



(b) Curved approach.

Figure 11.- Dwell times, dwell percentages, and transition percentages for curved vs straight-in approaches in segment 4. Absence of data indicates absence of pilot scan.

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16. Abstract

Newer generations of aircraft using advanced displays, better automation systems, and better electronics coupled with similar advances in ground navigation aids should allow pilots to perform precision advanced flight maneuvers, such as curved instrument landing approaches, which are not currently possible with a conventionally equipped aircraft. To assess the effect on pilot scan behavior of both advanced cockpit and advanced manuevers, a series of straight-in and curved landing approaches were performed in the Terminal Configured Vehicle (TCV) simulator at the Langley Research Center. Two comparisons of pilot scan behavior were made: (1) pilot scan behavior for straight-in approaches compared with scan behavior previously obtained in a conventionally equipped simulator and (2) pilot scan behavior for straight-in approaches compared with scan behavior for curved approaches. The results indicate very similar scanning patterns during the straight-in approaches in the conventional and advanced cockpits. However, for the curved approaches pilot attention shifted to the electronic horizontal situation display (moving map), and a new eye scan path appeared between the map and the airspeed indicator. The very high dwell percentage and dwell times on the electronic displays in the TCV simulator during the final portions of the approaches suggest that the electronic attitude direction indicator was well designed for these landing approaches.

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